Mitigating confusion: classification of road subtypes and socioeconomic and environmental impacts of roads in the Amazon

by

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ABSTRACT

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This paper recognizes the disconnect of road terminology present in current road ecology literature. The epistemological methods of First-Order Logic and the Q-Method along with political ecology are utilized to form a working typology of roads and their impacts, specifically centered in the Amazon. Following this, this work briefly discusses three unique cases studies that focus on different road aspects to display real-life examples of subtypes in the typology. The overarching goal of this study is to better organize the field of road ecology and help to mitigate negative environment and socioeconomic impacts in the future.

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MITIGATING CONFUSION: CLASSIFICATION OF ROAD SUBTYPES AND THESOCIOECONOMIC AND ENVIRONMENTAL IMPACT OF ROADS IN THE AMAZON

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INTRODUCTION

In 1998, Forman and Alexander declared "few environmental scientists, from population ecologists to stream or landscape ecologists, recognize the sleeping giant, road ecology." The field of road ecology, or the study of road systems, natural resources, and the environment (WTI 2012), has consequently grown, revealing the magnitude and complexity of roads' environmental and socioeconomic impacts. Since then, research demonstrates roads vary inherently, and as a result, a plethora of terms have been used to describe each unique type of road. The lack of unified definitions for each type of road create confusion within road ecology and related literature. Without a precise typology defining road subtypes and an understanding of the impacts resulting from each, comparative research becomes challenging. This proves especially important for policy makers who, without access to accurate information, are less likely to make the best choices concerning road development for each community and region. Until now, no one scholar has organized a modern typology of roads to facilitate the use of the extensive literature on the impacts of roads.

In developing countries, this lack of a concrete typology inhibits the ability of officials and scholars to evaluate social and environmental impacts that different roads inflict. For example, road construction in the Amazon has been on the rise, contributing to the increased colonization of remote areas, the over-extraction of valuable resources, a decrease in biodiversity, and the growing conflict between peoples' and their environments (Finer et al. 2009). To better mitigate these impacts, the diversity of roads must be entirely understood. Only then can decisions be best made on what type of roads to build and where to build them.

In this study, I organize the subtypes and establish common road definitions and uses of each while at the same time investigating the social and environmental impacts resulting from them. The first part focuses on an array of papers and authors within road ecology and attempts to define each road subtype based upon that scholarship. The latter section of this study center around three separate case studies: one in Brazil (road construction to promote colonization and industrialization), one in Peru (Madre de Dios and the paving of the Inter-Oceanic Highway), and one in Ecuador (road construction for oil access in indigenous territory). I review these case studies from a political ecology framework to demonstrate the mechanisms that formed the various roads as well as their diverse environmental and social impacts.

Although focused on road infrastructure in the Amazon, this typology should function across many regions, on a global scale, to unify road ecology literature (as well as other literature that takes roads into account). Today enough research exists to coalesce all of this information. Standardized road definitions and terms will allow road ecology to continue to purposefully, and strongly, progress.

METHODOLOGY AND THEORY

Overall, current road ecology literature utilizes topical variables in studies and analysis without unified boundaries defining precisely what each type of road entails. A number of studies mention varieties including (but not limited to): primary roads, secondary roads, unofficial roads, official roads, unpaved roads, paved roads, logging roads, etc.. By employing these terms, but granting them inconsistent properties, there exists a constant, inherent confusion within the discipline making it necessary to unravel and organize these terms into a structured typology. This process of deduction and reduction of road types requires the theories of epistemology, political ecology, and of course, road ecology be employed.

The majority of current work in most disciplines rests on traditional and given knowledge. "Knowledge gives particular shape, meaning, and discipline to our interactions with the world" (Cook and Brown 1999). Since this essay aims to create a logical typology of road types and their succession, the fusion of knowledge necessitates both the branch of epistemology and the framework of political ecology, social to biophysical, or human to environment, relations (Zimmerer and Bassett 2003). The prior provides the logic essential to simplify and organize this network/web of roads into a uniform descriptive typology. In addition, the utilization of the latter can unravel history and impacts, allowing origins to be clearly understood and helping to prevent negative impacts in the future (or even mitigate those presently existing).

Steup (2005) defines epistemology as "the study of knowledge and justified belief." Specific and defined methods must be used here in order to uphold end results. Two specific epistemological methods were utilized in this study: the Q-method and First-Order Logic. The Q-method, commonly used in conjunction with epistemology, correlates common variables between subjects (the 'subjects' in this case being roads) (Robbins 2000). By employing this method, a typology created through the exploration of "ongoing conversation and discussion" (132) can be facilitated. Here, these conversations derive from the published scholarly articles in road ecology and beyond.

In combination with the Q-method, First-Order Logic couples 'expressive power' (the 'conversations' mentioned above) with recognized computer based approaches. Logic can function as a systematic tool in instances where mathematical techniques cannot be used, or fail due to a lack of specific quantitative material (Peli and Masuch 1997). With the use of logic, verbal arguments (derived from theories) take on given formulas. These formulas then grant the ability to examine crucial properties, like consistency: a property absent from road ecology literature as a whole.

First-Order Logic requires a number of information sets, including the creation of consistent “names for objects in the domain” (Peli and Masuch 1997, 311), assignment of the relations and properties between these objects and quantification of these properties, the variables themselves, and by which means they logically connect to one another (Peli and Masuch 1997). These logical connections can be negative (denoting that objects are not equal), conditional (if-then/sometimes equal), biconditional (specifics, if and only if, grants equivalence), disjunctive (one or the other), and conjunctive (and, equality) (Peli and Masuch 1997). Each of these will be utilized and further delineated later on in this essay.

First-Order Logic also involves the analysis of background assumptions. This calls for a political ecology framework due to its roots in political economy and ecological analysis as well as its inherent interdisciplinary nature. Political ecology, addressing the complexity of “bio-cultural-political” (1) relations, here forms a common ground for the intersecting disciplines of epistemology and road ecology (Greenberg and Park 1994).

Rocheleau (1999) defines political ecology as “the social relations of power and the formation and functioning of ecologies and landscapes” (22). This relates directly to the origination and formation of roads on landscapes (*why* roads are built/ *who* builds them, *where* roads are built, and *how* they are used). Since much of political ecology centers around natural resource conflicts and the social issues therein intertwined (Baviskar 2003; Paulson et al. 2005; Schmink and Wood 1987; Schmink and Wood 1992), and because roads provide access to these resources, one cannot ignore the insight this framework possesses in the investigation of road-building.

Elaborating on this, “land conflict in the Eastern Brazilian Amazon results from power struggles over the region's abundant resources” (Simmons 2004, 184). With this in mind, Simmons expands, evaluating how these power struggles lead to the creation of an infrastructure made to extract and utilize resources. Put simpler, this addresses “land conflict in Amazonia in terms of frontier development processes” (Simmons 2004, 184). This resource competition produces turmoil; an ever-shifting ownership of land and of its riches as well as an ever-shifting ownership of roads and who controls their access upon construction.

Epistemological methods have been utilized in conjunction with political ecology studies before (Blaikie 1999; Robbins 2000; Bryant and Goodman 2004). Robbins (2000) uses the Q-method to determine the “most meaningful division in epistemology … that give[s] rise to contending accounts of nature and environmental change” (126). Here, Robbins distinguishes differences in the thought of local peoples and of the state (or governance). He then combines this with historical sequences to create a theoretical chronicle of environmental knowledge, constructed through power relations. Bryant and Goodman (2004) also employ parts of the Q-method, emphasizing how political articulations of policy activity shape state behavior and its overall role in ecology.

This analysis follows along similar lines, but instead of using thoughts and conversations (Robbins 2000), or political articulations (Blaikie 1999; Bryant and Goodman 2004), utilizes literature on the impacts of roads. Combining the Q-method with political ecology, the terms used to denote road types in road ecology are based largely on the four variables stated earlier: *why* the roads in question are built, *who* built them, *where* they are built, and *how* they are used. These same variables, while forming the definition of roads, often determine their impacts as well. To categorize roads and create an ordered typology of roads, one cannot simply dissect their effects and group them as such. Political ecology, which expands upon these four variables delineated through the Q-method, must then be combined with First-Order Logic.

Simplified, political ecology illustrates variables that are then delineated by the Q-method into why, who, where, and how. Then, First-Order Logic organizes and pairs this material. The political ecology framework surrounds the Q-method and First-Order Logic employed by this study to define and categorize roads. I analyze the primary builders of each road (why/who), the primary uses of each road (how), and the order in which these roads come into being (where). While stated simply here, the process requires the common language and discussion of scholars (the Q-method), logical deduction of this language (First-Order Logic), and historical sequences/ purposes of road construction (political ecology).

To illustrate this process, reference the secondary road deconstruction shown in Figure 1 below.

Figure 1: Logic of Naming

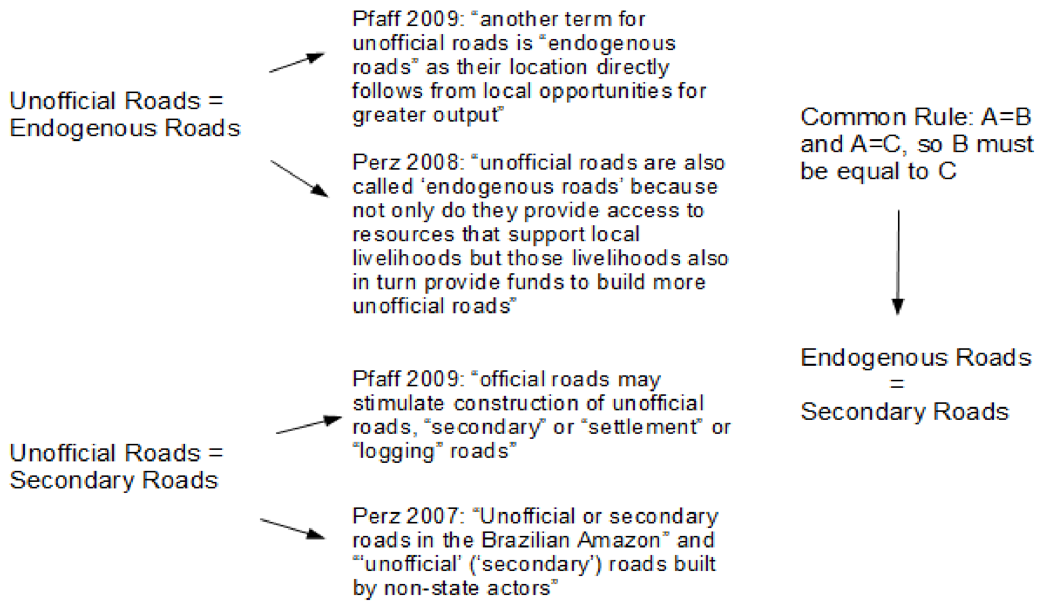


Figure 1: This figure illustrates a simple example of how the Q-Method, First-Order Logic, and political ecology come together to narrow down road terms and definitions.

This sequence exercises the Q-method to discover and order common names taken from 'conversations', or publications. The First-Order Logic method functions here to show unofficial roads equal endogenous roads and unofficial roads also equal secondary roads. Ifthese facts are true, then endogenous must be equivalent to secondary roads. In First-Order Logic terms, their definitions are 'conjunctive' (Péli and Masuch 1997).

This diagram also uncovers political ecology's role. Words and phrases, such as “livelihood”, “opportunities”, and “greater output”, display how economies and politics shape the road-construction process. Also seen are the derived analytical steps mentioned earlier, shown below:

1. 'why are they built'- to access resources (Perz et al. 2008)
2. 'who built them'- non-state actors (Perz et al. 2007b)
3. 'where are they built'- usually adjoining official roads (Pfaff et al. 2009)
4. 'how are they used'- to provide access to resources and support local livelihoods (Perz et al. 2008)

The answer to these questions coalesce to form a common definition of secondary roads: roads, built by non-state actors, that may extend from primary/official roads to provide access to resources and support local livelihoods.

Of course, it must be noted that this represents a simple model. These deductions possess many more complexities than displayed here. But for practical purposes, this proves a good representation of how the methodology used in this analysis operates.

This method categorizes the typology employed in the analysis portion of this paper. Its existence is crucial prior to discussing the environmental and socioeconomic impacts that result from the installation of different road types. All four analytical questions listed (*why* roads are built, *who* built them, *where* roads are built, and *how* they are used) hold importance in the infrastructure of, and the interactions in, the Amazon.

ANALYSIS PART I: ROAD TERMINOLOGY AND TYPOLOGY

A review of over 50 publications of road ecology literature concerning Amazonia revealed many road-type terms including: primary, secondary, tertiary, main, access, official, unofficial, municipal, endogenous, logging, feeder, and spur. Some main points of contention to be discussed include: confusion resulting from fact omission, micro versus macro scale literature, and common definitions. All of these issues and more can be lessened with an ordered typology of roads.

The previously explained methodology resulted in Table 1 below. This table displays three road-type groupings, derived from the extensive list of subtypes used in the common road ecology and land change science literature. This will serve as a reference point for much of the following subtype theory discussion and problem-solving.

Table 1: Roads Grouped by Subtype

Road Subtype	Otherwise known as:	Definition/ Fact most stressed	Common environmental impacts	Socio-economic Impacts	Other common characteristics*	Current Information	Examples in Case Studies
Primary	Official; Main	Federal or state government built	Natural resource removal; forest clearing	Reduce transportation cost for loggers and colonists	Connect cities; spur secondary construction; mapped	Often improved roads rather than newly built	Highway: Cuiaba-Perto Velho (Brazil)
Secondary	Unofficial; Access; Municipal; Endogenous; Logging; Settlement; Feeder**	Built by loggers, colonists, local interest groups, etc.	Natural resource exploitation; forest fragmentation; over-hunting	Logger to colonist interactions; Invasion of indigenous territories	Seasonally impassable; extend from primary roads; often unmapped	Being rapidly constructed; form dense networks	Access: Maxus and Auca (Ecuador)
Tertiary	Unofficial; Logging; Flange	Do not connect directly with primary roads	Deforestation, ecosystem degradation		Usually built for harvest; not maintained; unmapped		

*Note: These characteristics do not exist for every road in each category, but do show up often.
**Note: Common literature still disputes this term in certain cases.
Primary sources used in this table: Southworth et al. 2011; Forman et al. 2003; Pfaff et al. 2009; Perz et al. 2007A; Perz et al. 2007B; Millikan 1992; Finer et al. 2009; Hiraoka and Yamamoto 1980

Many authors utilize the term 'primary roads', while others employ either 'official roads', 'main roads' (Table 1), or, in a few cases, 'development roads'. For all practical purposes, these appear to be nearly the same. Forman et al. (2003) describe primary roads as government built 'major federal and state arterial highways and freeways' (197). Primary roads are generally government mandated, like the Trans-Amazonian and the BR-364 highways (Pfaff 2007; Pfaff et al. 2009). Similarly, official roads maintain a corresponding definition (Perz et al. 2007b). In fact, Pfaff et al. (2009) use the terms 'official' and 'primary' interchangeably while discussing the effects of feeder roads:

> 'Along such official roads as the Transamazon and the BR-364, the state built feeder roads … the feeders ran up to 10 km in both directions from the primary roads' (107).

Southworth et al. (2011) support the idea that main roads equal highways in a study of the MAP region (Madre de Dios (Peru), Acre (Brazil), and Pando (Bolivia)). The study focuses on paved and unpaved roads within the region, focusing on the Inter-Oceanic Highway.

Southworth et al. (2011) also demonstrates how easily confusion surrounding road terminology can be created. The authors state no main roads exist in this region of Bolivia; however, a figure inside the publication maps the rate of deforestation as compared to the distance from the nearest 'highway' in all three countries (Southworth et al. 2011; 1059). Luckily, further research shows that the interoceanic highway runs through Brazil and Peru, along the border of Bolivia (BIC 2012). If additional research had not been conducted to discern this fact, one may wrongly believe main roads are not equivalent to highways. Without a road typology, confusion arises from the simple omissions like this.

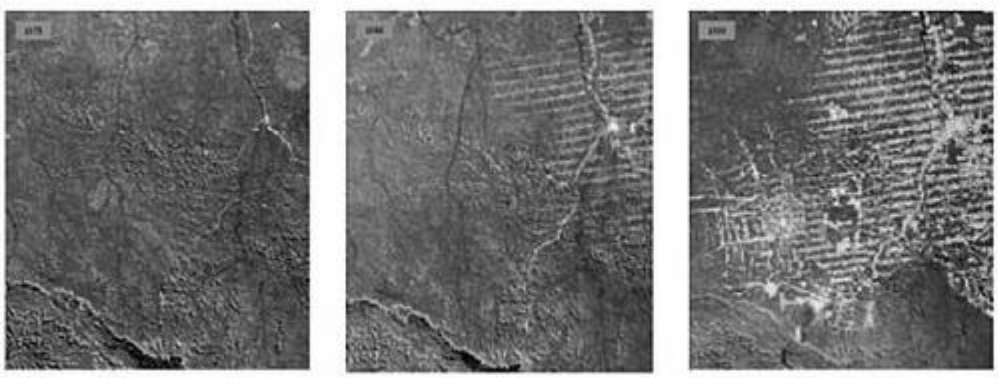
Adding to the variety, confusion can stem when some authors utilize terms on either micro or macro scales, such as with logging practices. For instance, Uhl and Vieira (1989) discuss primary roads (along with secondary and tertiary roads) on a micro scale. They define primary roads as those to which the trees are brought (Table 2) and secondary as those from which trees are extracted. However, as Asner et al. (2006) reports on a macro level, almost all logging occurs within 25km of main roads (which, as previously stated are equivalent to primary). Having read both papers, secondary and tertiary road can be assumed into Asner's macro model. If both are not read, however, a reader could confuse the role of the primary road. Reading only Asner et al. (2006) could lead one to believe primary roads take on the role that Uhl and Vieira (1989) show us secondary roads truly play.

Table 2: Logging Road Subtypes

Subtypes of logging roads	Otherwise known as:	Definition most utilized	Other common characteristics
Primary	Main; Official	Where trees are dragged to and mass transported	Flat-bed truck accessible
Secondary	Unofficial; Spur	Attached to both primary and tertiary roads; used to extract log resources	The main in-between avenue
Tertiary	Unofficial; Flange	One-time-use road, used to retrieve further logs	Often disappear within 5 years

Primary Source: Uhl and Vieira, 1989

Often constructed as extensions from primary roads, secondary roads (Forman et al. 2003) present the most difficulty and confusion on a macro scale. Other names include unofficial roads, access roads, municipal roads, endogenous roads, logging roads, settlement roads, and perhaps feeder roads (although, some authors dispute this last one) (Table 1). The most prevalent definition unifying secondary roads appears to be that they arise due to non-governmental entities; however, the literature varies on this prominent point. In fact, two authors (Pfaff and Arima) refer to the same set of secondary roads and maintain differing boundaries of how to define them/who built them.



Source: Landsat data 1975, 1986, 1999; USGS Data Center/UNEP, 2002

Figure 2: *Deforestation in Rondônia, Brazil, caused by road construction followed by colonization, logging, cattle ranching and crop farming*

When the Brazilian government began constructing roads with the dual purpose of infiltrating the Amazon and decentralizing the urban population of Brazil, they also installed feeder roads extending 6-10km out every 5km along some of the the main highways (creating a “fish-bone” effect as shown in Figure 2) (Pfaff 2007; Arima et al. 2005; Sayer 2005). Arima et al. (2005) describes these as secondary roads “constructed by the federal government as access spurs … off the federal highway” (527). However, Pfaff et al. (2009) relates that unofficial roads, also “called secondary, settlement, or logging roads, depending on who constructs them, are created by non-state actors such as loggers and colonists” (6). In Pfaff et al's 2007 publication, he discusses the same set of roads Arima et al. (2005) mentions. He also acknowledges they were built by the government, but he adds they have now been 'unofficially' extended by colonists in the region, hence now deserving the 'unofficial' road classification. Yet another study tries to avoids this run-in by calling these primary roads 'development roads' and the secondary roads 'settlement roads' (Walker 2003). Still, much of the current literature considers these terms (secondary roads and settlement roads) as equivalent (Arima et al. 2005; Aronson 2007; Pfaff et al. 2009; Stone 1973).

These authors state similar facts about the roads in question, except exactly what to call them. All state that, initially, the government built these roads, but while Arima et al. (2005) labels them as secondary from the beginning, Pfaff et al. (2007), since he has defined secondary roads as created by *non-state* actors, cannot say the same. Trying to get around this complication, he utilizes the term 'unofficial'. Now, however, since secondary and unofficial have proven equivalent subtypes, these statements are incongruous.

Here, I propose that they be called secondary in all literature. The fact that they did originate from state actors should make this statement contradictory. The key: non-governmental players did extend them, they are built as offshoots from primary roads, and they were built with the purpose of providing access to resources and supporting local livelihoods. In reference to the stated definition in the methodology section of this paper, these particular roads fill 3.5 out of 4 of the requirements necessary to be deemed secondary roads. Hence, it is close enough to override and eliminate further incongruity in the literature.

In addition, several other examples of road ecology literature support the conclusion that unofficial roads include secondary roads (Perz et al. 2007a; Uhl and Vieira 1989; Forman et al. 2003; Millikan 1992; Finer 2009; Hiraoka and Yamamoto 1980; Brandano and Souza 2006). Perz et al. (2007a), writing on the Amazon, states that “'unofficial' ('secondary') roads built by non-state actors are expanding rapidly relative to 'official' ('primary') roads” (530).

This statement brings yet another issue to the fore: whether secondary roads need be attached to primary roads in order to deserve the 'secondary' classification. In Table 1, see '*often* attached to primary roads' written in regards to this debate. While secondary often exists in this manner, some secondary, or 'access', roads have been constructed without primary road connection (Uhl and Vieira 1989; Forman et al. 2003; Perz et al. 2007b; Pfaff et al. 2009).

Serving as a prime example, the Maxus Road, an access road built by the Texaco-Gulf oil company in Ecuador, begins in a town built along the shore of the Rio Napo River (Donahue 1998). Many terms have been utilized to categorize this road, contributing to the uncertainty of the 'secondary road' concept. Some authors call the Maxus an 'endogenous road' (Perz 2008), some an 'access road' (Arima et al. 2005; Finer et al. 2009; WCS), and others an 'unofficial' road (Perz 2008; Pfaff et al. 2009). Still, other literature refers to the Maxus Road simply as a 'major road' (Finer et al. 2009). Interestingly, even though this road fits within the secondary definition of being built by a non-governmental entity, no literature directly calls it 'secondary'. Only through the collection of like-terms and the road's origin can it be deemed 'secondary' here.

In support of this deduction, view Figure 1 in the methods sections and Figure 3 below.

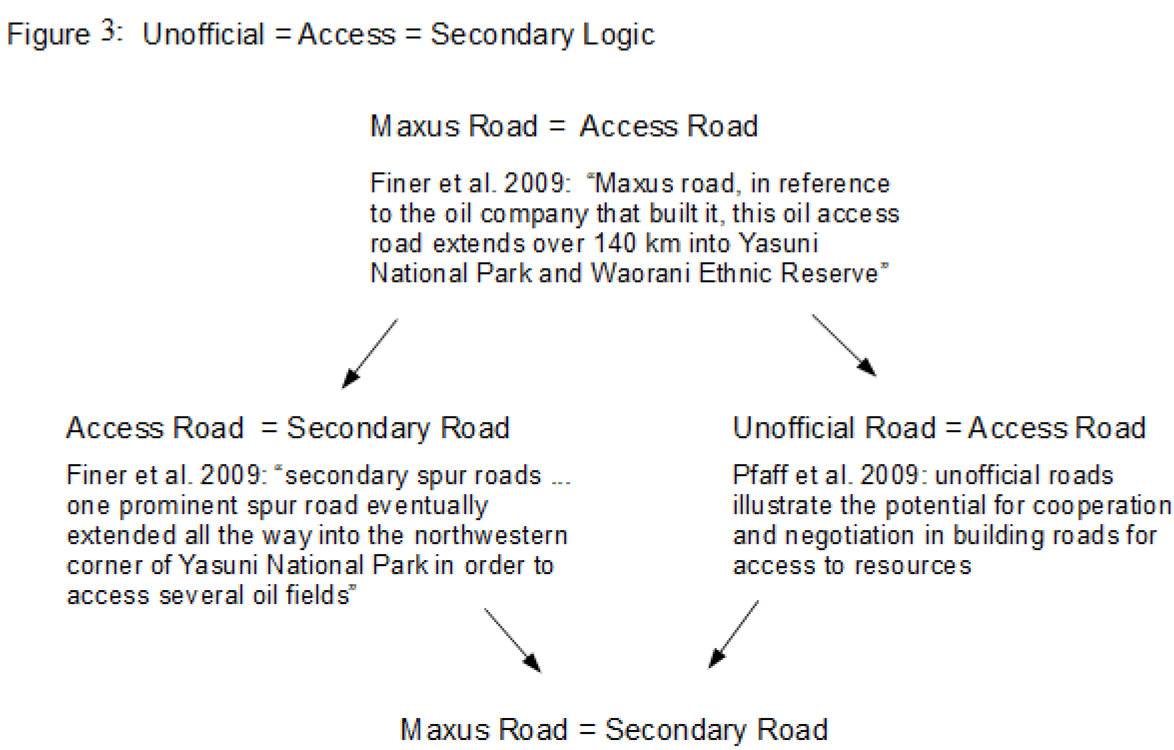


Figure 3: An elaboration on the conclusion that Maxus Road can be placed within the 'secondary road' subtype.

Figure 1 illustrates a simple pattern of the strategy and logic used to pair road subtypes. This case represents an unusually simple and straightforward example; normally these pairing contain flaws and diverse characteristics, and definitions are mixed and matched (for instance, the feeder roads mentioned earlier).

Using a process similar to the Figure 1, I define tertiary roads as roads not directly connected to primary roads, built by non-state actors (like secondary), and used for *temporary* access to resources. Between them, a secondary road usually exists, as seen in the Figure 4 below. Other names for tertiary roads (Table 1) include flange roads and logging roads; although, differences between tertiary and secondary logging roads exist. While tertiary logging roads provide only one-time, or limited, use “to pull out a single tree bole” (Uhl and Vieira 1989), secondary roads are more often trafficked. Tertiary use oft times “end[s] when profitability does” (Pfaff et al. 2009).

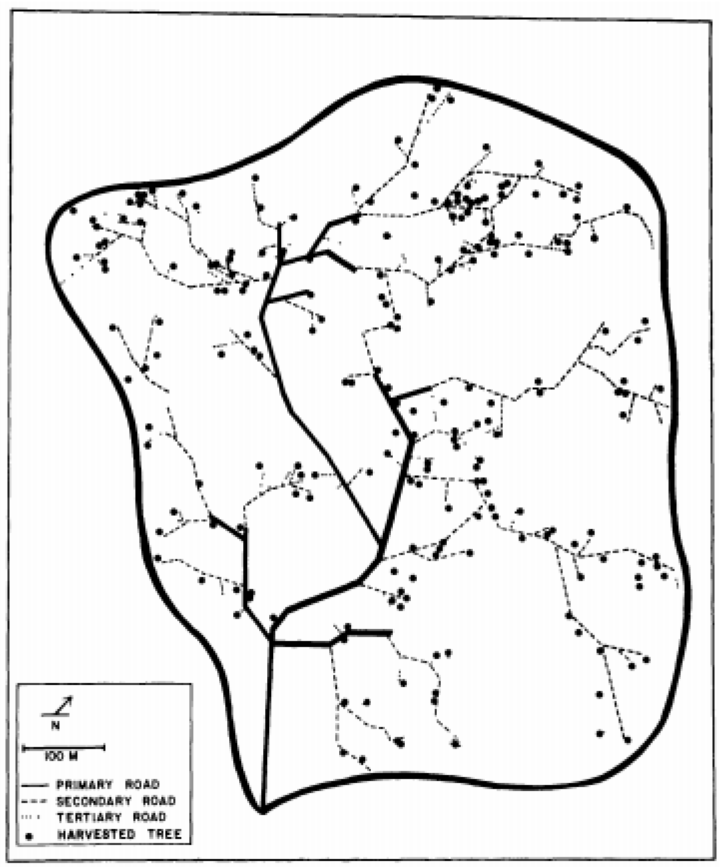
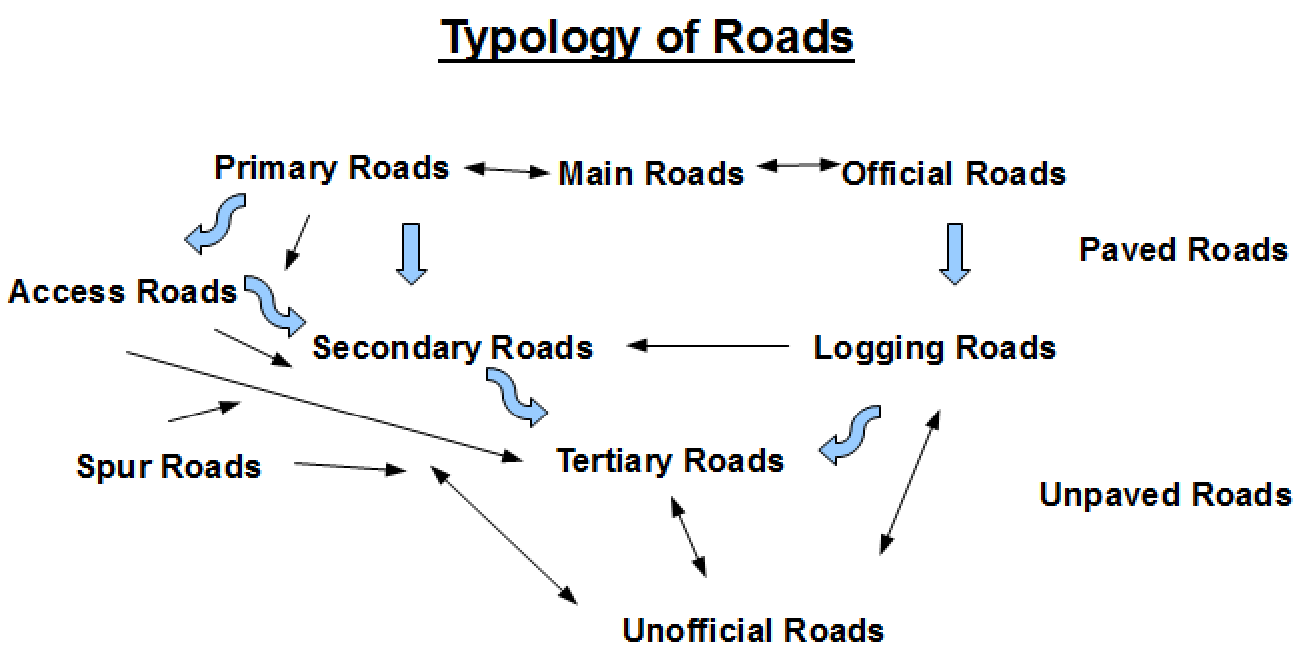


FIGURE 4: The network of primary, secondary, and tertiary roads established to selectively log 52 ha of rain forest near Paragominas, Pará, Brazil. The line encircling the logged site is not meant to depict a road, but rather was added to provide definition to the site.

Essentially, road classifications are processional and dynamic: they do not stagnate over time. A series of factors affect possible changes to road definitions, including road abandonment/closing and road-paving, discussed in Part II of this analysis.

ANALYSIS PART II: PAVED VERSIS UNPAVED

In addition to the various subtypes based on builders and uses, roads possess additional variables that can alter or modify each subtype. For instance, if paved by the federal government, a road may shift from secondary to primary. Also affecting secondary/primary determination, roads' uses and impacts vary depending on whether the road is paved or unpaved. The chart below displays how this variable fits into the road typology configuration.



The thick arrows illustrate which subtype stems from which. The thin arrows indicate that the roads are equivalents, aka, the same subtype under a different name. Thin arrows with 1 head pointing A to B, signify that A=B but B is not always equal to A.

Here are a few statements derived by this typological chart using First Order Logic:

- Access roads often sprout off of, or 'come from', primary roads. Note, however, that a primary road can be built as an access road, but just any access road cannot be deemed a primary road.
- Access roads are usually secondary roads (since they stem from primary roads like secondary roads do), but access roads (when primary) can also 'grow' secondary roads. A random secondary road cannot be called an access road.

- Thus, access roads are conditional to both secondary and primary roads.
  - Access roads are placed in the secondary category in Table 1 because the vast majority of access roads are secondary.

Paved roads and unpaved roads possess no arrows in the typological chart above given these factors display extreme variability. More often than not, paved roads show up in the primary and secondary block of roads (as shown by the placement of 'paved roads' above). Similarly, 'unpaved roads' occupy the space between secondary and tertiary roads because many secondary roads and most tertiary roads remain unpaved. Paved and unpaved roads possess their own qualities to be shown separately from those in Table 1 (Table 3 below).

Table 3 Paved versus Unpaved

	Environmental Impacts	Socioeconomic Impacts	Other common characteristics	Comparison	Examples in Case Studies
Paved	increases roadkill; accelerates deforestation; pollutes waterways (mining and run-off); increases risk of fire	Increases migration; brings in interest groups; invasion of indigenous lands; heightens land value; increases drug-traffiking and violence	Often followed by rapid unpaved road construction; often primary roads	Offer greater accessibility (through wet season); reduces transportation costs and time	Acre (Brazil); BR-364 highway (Brazil)
Unpaved	Quick access for resource extraction; erosion run-off into waterways	Open undeveloped areas, less available imported food	Often constructed first, lending access; can become paved; expanding at a fast rate; mostly secondary and tertiary roads	Lower impact on wildlife, higher cost for importation of goods; usually less deforestation	Lago Agrio (Ecuador)

Primary Sources: Forman et al. 2003; Southworth et al. 2012; Perz et al. 2008; Perz et al. 2011; Mendoza et al. 2007; Switalski 2005; Adeney et al. 2009

As hinted in the typology chart, 'paved or unpaved' can often guide road classification, especially for roads on the cusp between two types. For instance, the characteristic of permanence commonly distinguishes secondary roads from tertiary roads. Secondary roads generally supply more use (Theuerkauf et al. 2003) and thus, remain longer than tertiary (tertiary roads frequently return to the forest quicker, especially tertiary logging roads) (Foster et al. 1999; Uhl and Vieira 1989). A road that has been paved, then, obviously lasts longer. In turn, following paving, a road becomes utilized more often (Southworth et al. 2011). Thus, a longer-lasting, busier road has more likelihood of being classified as secondary than tertiary.

This brings up yet another factor to take into consideration: when paved, a road can be converted from tertiary to secondary, or from secondary to primary (Perz et al. 2011; Southworth et al. 2011). The subtype a road starts as may not necessarily remain as such (although, demotion of a road, except back to forest as with tertiary roads or closed roads, rarely occurs).

CASE STUDIES

Road formation and type often stem from who possesses more power within a community, region, or group of stakeholders and what occupies the most importance for them. What the winning stakeholder desires determines *why* a road is built, *where* a road is built, and *how* it is used. Having said this, different road types inflict various impacts. Each of these case studies, in Brazil, Peru, and Ecuador, illustrates the powerful stakeholder point. The wish of the Brazilian government to decentralize its urban populations and open labor markets within the Amazon (to extract more valuable resources) resulted in a series of new primary roads (Arima et al., 2005; Asner et al, 2006; Mendoza et al., 2007). The construction of secondary access roads in the Oriente of Ecuador enabled companies to extract oil, but at the expense of indigenous peoples (encroachment of territory) and a national biosphere reserve (Thomson and Dudley, 1989; Hiraoka and Yamamoto, 1980; Finer et al., 2009; WSC, 2010; Suárez et al., 2009). Paving the Inter-Oceanic Highway in Peru allows easier transport for industry and migration, but has accelerated deforestation within the region (Perz et al., 2011; Zambrano et al., 2010; Mendoza et al., 2007; Southworth et al., 2011).

Now that we have a designated typology of roads, we can elaborate on their impacts and origins using these case studies. As described using the uniform descriptions posited above, each road will be categorized as primary, secondary, or tertiary, but may contain another to further classify it; for instance, secondary oil access road.

CASE STUDY 1: PRIMARY ROAD CONSTRUCTION IN BRAZIL

In the 1970s, the Brazilian government formulated a plan called PIN (National Integration Program, or *Programa de Integracao Nacional*) to decentralize its urban population and open up the Amazon. In collaboration with the World Bank, the government originally built the Trans-Amazonian Highway (BR-230) and the Cuiaba-Perto Velho Highway (BR-364) (along with others) to improve socioeconomic conditions (Millikan 1992; Pfaff et al. 2009). They attached (secondary/primary) feeder roads to these primary roads for colonization, later to be extended by colonists to secondary/tertiary roads. This represents a peculiar instance, since here, the government acted as a force to build secondary roads, thus speeding up the natural process and skewing the standard secondary definition. These feeder roads are cause for much contention within the road ecology discipline as well as road definitions, though unintentionally.

When a primary official road is built, almost inevitably smaller secondary roads expand all around it. This expansion is described by the statistic that within 100km of a new, primary road 90% of deforestation occurs (Arima et al. 2005). Though deforestation was anticipated here, the ancillary impacts were not. Brazil's purpose was colonization and occupation of the Amazon and thus, Brazil facilitated migrations from cities by way of these roads. Unfortunately, rather than improve socioeconomic conditions for the migrants, this ultimately ended in the production of 'forest slums', similar to those occurring in the abandoned infrastructure of cities. This very thing occurred in Rondonia, Brazil, the focus of this case study (Millikan 1992).

In 1960, the population of Rondonia stood at 70,000. This population of rubber tappers and a few others maintained the rainforest virtually intact; however, this began to change when the Brazilian government and the World Bank finished building the primary Cuiaba-Porto Velho Highway in 1978. Built to encourage occupation of the Amazon, small farms, and colonization, the National Institute for Colonization and Agrarian Reform (INCRA) distributed 100 ha plots for little to no cost (Anderson et al. 2002). The instant increase in migration only displayed a glimpse of the multitude to come.

Between 1979-1984, Brazilian officials furthered construction on the Cuiaba-Porto Velho Highway and upped its permanence by asphalting it (under the Polonoroeste project) (Mendoza et al. 2007). In addition, they sped up the colonization process by providing land titles, small-farmer settlements, and public health care. Largely due to the newly paved road (allowing for easier transport) and a growing economic crisis in Brazil, immigration increased rapidly. In fact, the number of people flowing into Rondonia inflated threefold. Landless families more than doubled by 1985 (Millikan 1992). Demand for plots increased at a rapid rate, quickly exceeding the available supply (Anderson et al. 2002).

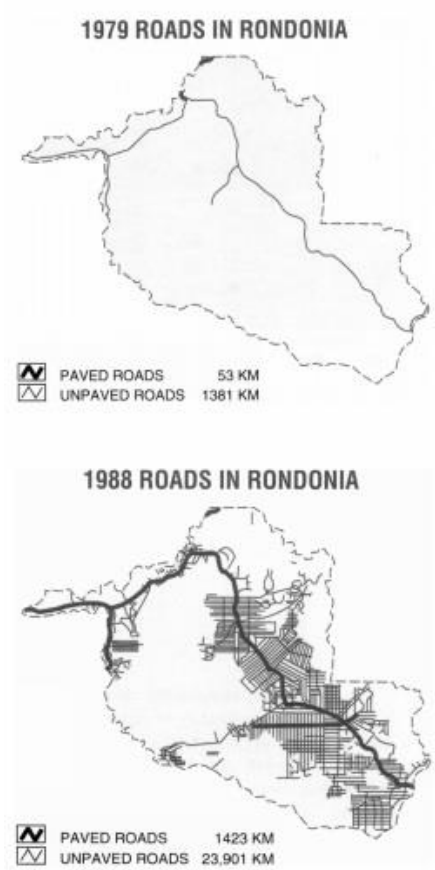


Figure 5 : Displays the secondary roads that sprouted from the Rondonia's primary road in the 9 years following the decision to pave (Wilbanks 1994).

With fertile lands grew increasingly scarce, large landholders began to take over the more fertile soils, while small farmers were left with little. The institution formed to handle these encroachments, INCRA, did not hold enough power to prevent these expropriations. Land values rose due to the heightened demand and further construction of secondary roads multiplied as more settlements for small farmers and new immigrants were needed (as show in Figure 5 above and Figure 6 below). These developments greatly threatened indigenous Amerindian reserves and fragile forest ecosystems. By 1988, not only had roads increased by 1600% since 1979 (Gardner 1991), but 85% of the area's indigenous population had perished from both disease and violence even as a fifth of the rainforest was destroyed (Nepstad et al. 2001).

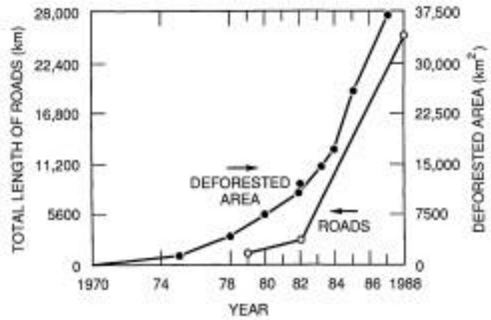


Figure 6: Relationships between deforestation and road construction in Rondonia, Brazil, 1970–1988. Source: Southworth n.d.

Adding to the impact, FUNAI, the National Indian Foundation, and IBDF, the Brazilian Institute for Forestry Development, were characterized by political and administrative weakness during this crucial time, allowing for easier invasions into these delicate indigenous territories (Millkian 1992).

Because of the newly-taken-lands' location, by 1986, a land-use survey sponsored by the World Bank uncovered that cattle-ranching rather than farming occupied 46% of the cleared land in Rondonia, 30% grew annual crops, 8.5% bore perennial crops, and at least 16% had been abandoned. Cattle-ranching degrades soil, uses more land and less labor, and generally continues clearing more forest once land productivity decreases (due to the degrading nature of cattle pastures) (Hecht, 1992).

Also contributing to the immense deforestation of the area, 17% of all roundwood extraction in Brazil occurs in Rondonia (Arima et al. 2005). This practice was born from the primary road, but occurs primarily off of secondary and tertiary roads. Here, loggers and colonists work both with and against one another, displaying the complex political ecology of rainforest roads and timber resources.

These secondary logging roads have something in common with farmer colonists: both clear land and extract resources. Claiming land in the Amazon calls for “permanent productive land use” (Pfaff et al. 2009, 7). For loggers, this poses a problem since their strategy is often to extract logs and then, move to the next plot. Colonists, however, can more easily claim lands for agricultural use, thus, those with poor road systems often make deals with loggers. Loggers can extract timber from their land and then, the colonists can utilize the resulting roads. Loggers receive legal protection while colonists receive roads (Pfaff et al. 2009).

On the other hand, social tension frequently occurs between these same two players. Loggers often wish to avoid rivers and minimize costs, and due to this build roads in functional patterns dictated by topography and timber location. Colonists, on the other hand, would rather have straight roads to their plots (Perz et al. 2007a, 534). The bigger conflict here, however, happens when a logger wishes to build a road through colonist land in order to obtain access to a remote area (Arima et al. 2005; Perz et al. 2007a; Pfaff et al. 2009; Messina and Walsh 2001). In addition to conflicts with colonists in this regard, loggers also sometimes breach state forest borders as well as indigenous reserves.

To sum up the above material, power sat in the laps of the Brazilian government and the World Bank. Wishing to improve economic conditions and utilize forestland, they constructed a primary road. Here, the Brazilian government, the World Bank, and those individuals wishing to exploit the untouched areas of the rainforest represent the winning stakeholders. The losing stakeholders include the indigenous peoples of the region, rainforest advocates, and the forest itself.

These primary roads, built throughout the Brazilian Amazon, resulted in both environmental and socioeconomic impacts. Environmental impacts include deforestation, land degradation, and habitat fragmentation (Laurance et al. 2001). Socioeconomic impacts encompass overpopulation of the regions (in regards to land availability particularly), abandoned and slum-like areas, tensions between loggers and other actors, and land conflicts between small farmers and large landholders. Truly capturing the issues at hand, following the completion of this paved, primary road, Rondonia's population grew to over 1.2 million by 1996 (Anderson et al. 2002), more than 17 times its population of 1960.

CASE STUDY II: OIL ACCESS ROADS IN ECUADOR

In the Amazon, the battle over roads and the introduction of new people and practices has been an ongoing conflict. The victory usually goes to those who hold the most power. More often than not, large companies, loggers, and the pull of the global economy usually win the struggle. As a result, secondary access roads intrude not only on national reserves, but also into land occupied by indigenous peoples. An example of such a case exists in the Oriente region of Ecuador: called the most biodiverse area in the world (Finer et al. 2009). Since the mid-1900s secondary access roads built by oil companies have spurred colonization, deforestation, and over-hunting within the territory of the Waorani indigenous people, disrupting their culture and degrading their lands. Now the region is “fraught with tension and frequent conflicts as a complex network of stakeholders and powerful economic forces jockey for access to the area’s renewable and petroleum resources” (WCS 2011, 7).

Before oil companies rolled in, the Oriente remained fairly untouched by urbanization and deforestation (Hiraoka and Yamamoto 1980). After the Texaco-Gulf oil company constructed their first secondary access road in the area of Lago Agrio, migration increased drastically, thus commencing a cycle to be repeated throughout the area (Perz et al. 2011; Pichon 1997).

Conflict began erupting between indigenous peoples and the oil company early on in the 1900s. When Shell began operations in Waorani Territory in the 1940s, the Waorani launched attacks on the oil workers until finally, Shell abandoned the area in 1950. The Waorani triumphed in the first battle, but Shell did not give up. When a polio epidemic hit the indigenous group in 1969, Shell quickly commenced further oil exploration in the territory (Finer et al. 2009).

Even following the creation of Yasuni National Park in 1979, the government did not prevent the oil companies from entering and constructing roads in the reserve and in the indigenous peoples' territory (Rudel 1983). In fact, in the early 1980s, oil companies built a secondary access road, the Auca road, inside of Waorani Territory. Following this, the Ecuadorian government leased out oil blocks in the northern section of Yasuni National Park (Finer et al. 2009).

Due to the ensuing attacks indigenous groups made on workers, the government finally granted a small area of land for the Waorani Ethnic Reserve. This success for the indigenous group proved short-lived when the government decreased the size of the Yasuni National Park to allow for more oil extraction (Finer et al. 2009).

In 1992 another secondary access road, the Maxus road, began, and by 1995, ran through both the park and the indigenous reserve. In 1996, the government proceeded to lease an oil block within the park to yet another oil company. At the same time, a group of indigenous peoples organized to file a class action suit against Texaco-Gulf in the US due to their actions in Ecuador.

When considering how power affects the formation of roads, a central point exists: the inequality (during this time period) of how the government permitted oil companies to encroach upon lands of its own indigenous populations demonstrates the role that power and wealth play in road construction and resource extraction. Once the inevitable socio-environmental impacts increase, so does inequality. Here, oil companies won at the expense of indigenous peoples.

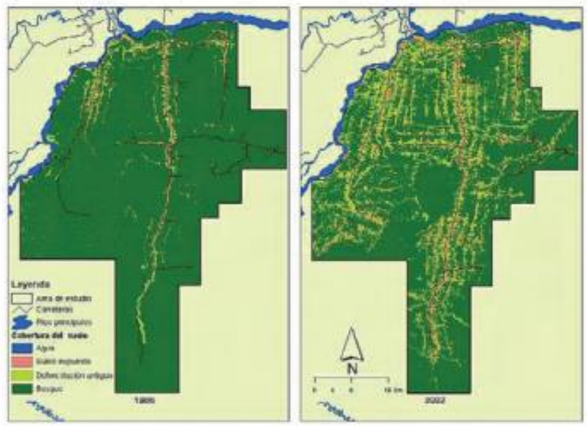


Figure 7. In the Auca Road study area, between 1986 and 2002, the percentage of forest converted to other uses reaches 23% of the total polygon area.

Numerous secondary roads sprouted off of the Auca road, whether built by the colonists flowing into the region or the loggers (Barbieri et al. 2005) (Figure 7 above (WCS 2011)). In fact, over 15 illegal logging camps existed within the Zona Intangible, a zone formed to protect land and indigenous peoples, as recorded in a 2005 survey (Finer et al. 2009). Between 1970 and 1990, forest cover fell from 100% to 59% in the Auca Road area (Bilsborrow et al. 2004). Figure 7 above displays the tremendous deforestation effect that the secondary access roads brought to the region.

Loggers and colonists began fighting the indigenous peoples for control as well, showing a few of the indirect impacts these secondary oil access roads inflicted (Gray et al. 2008). Even when colonists were barred from the Maxus Road, the lives of the indigenous peoples in that area changed due to the road's easy transport system. Perz et al. (2011) discuss ecological 'memory' of indigenous peoples, “collective memory to retain longstanding resource management practices” (Perz et al. 2011). Evidence of the fading 'memory' appears with the way the Waorani and other indigenous peoples in the area began using the Maxus Road: as a transport system to bring bush-meat to the market place located at the end of the Maxus Road and the Rio Napo River (just outside of the reserve), depleting rare animals and overhunting others (Suárez et al. 2009). The practice of selling wildlife is illegal and although the authorities are aware of these activities and the location, they have not yet done anything to prevent it (Finer et al. 2009; Grossman 2011).*

*Recently, the Wildlife Conservation Society has begun a series of programs to try to teach the Waorani people conservation techniques and well as other trades. They hope this will help prevent some of them from continuing to over-hunt and illegally sell bush-meat.

The beginning of a tertiary road built off of the secondary Auca Road

The end of the tertiary road above, most likely a logging road.

Figure 8: A tertiary road extends from the secondary access Auca Road (GoogleEarth).

Deforestation, habitat fragmentation, overhunting, and land conflicts represent just a few of the numerous environmental and social problems that ensued. The secondary oil access roads in the region formed due to the power oil companies hold as well as the value of oil itself to the global economy. Once there, these, and roads like it, allow an influx of migrants and loggers, stirring up more social conflict and further degrading the tropical forestland.

CASE STUDY III: PAVING THE ROAD IN MADRE DE DOIS

Many road ecologists have already stated that paving primary roads promotes the expansion of secondary unofficial roads, raises land values, and mitigates the costs of extracting natural resources (Chomitz and Gray 1996; Perz et al. 2008; Mendoza et al. 2007; Soares-Filho et al. 2006; Southworth et al. 2011). Here we will examine this element, as well as other effects paved and unpaved roads have and how they differ, using the case study of the Inter-Oceanic Highway in Peru. This primary road also runs through Brazil, but to ensure focus on the variable of paving, and to avoid possible cultural and governmental manipulation of impacts, we will focus on only one country, Peru. In addition, in Peru some sections are already paved, while others are still in progress, and still a portion remain unpaved.

The paving process all began in the early 2000s, meaning impacts are still developing (Oliveira 2007), but already certain environmental changes have begun appearing: deforestation, over-exploitation of resources, land conflicts (due to increased migration), and general forest degradation. Many stakeholders are interwoven into these conflicts, including small farmers, logging firms, indigenous groups, large-scale ranchers, and urban populations (Mendoza et al. 2007). With all of this

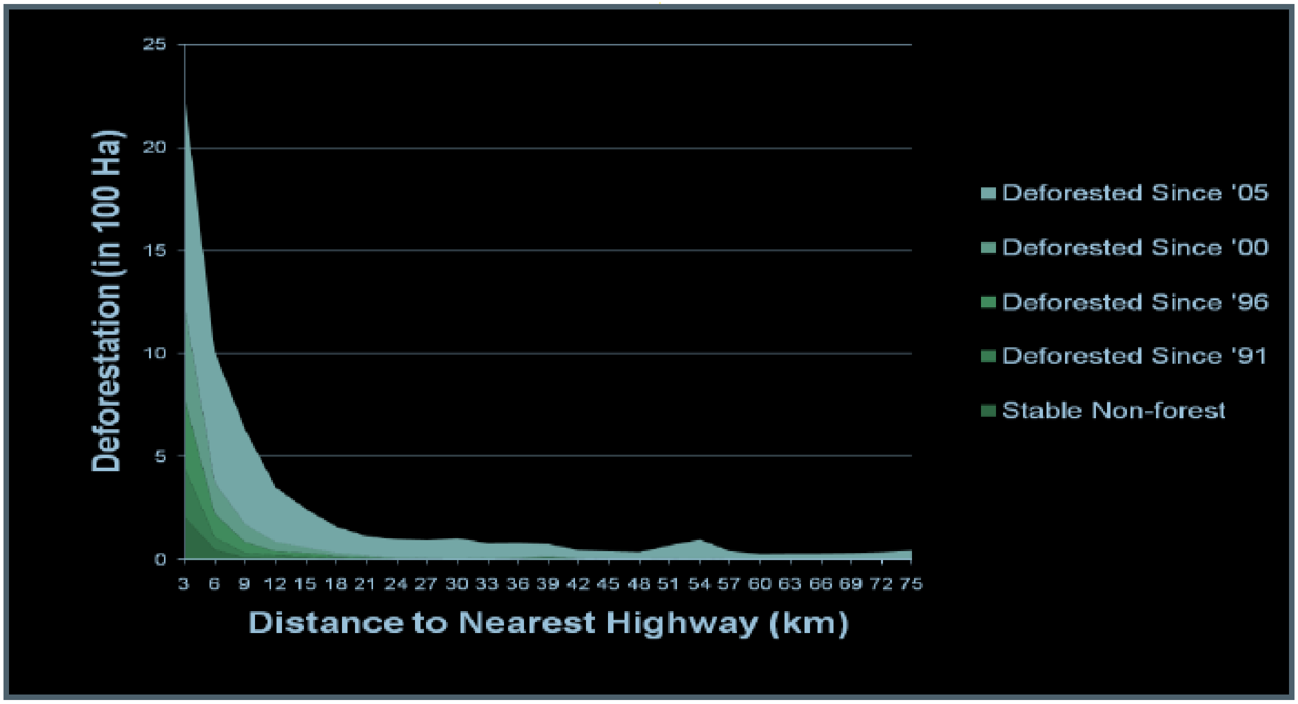


Figure 9: The rate of deforestation throughout time and within certain distances from the Inter-Oceanic Highway in Madre de Dois, Peru (Southworth et al. 2011).

in mind, analysts conducted a simulation into the future that predicted (that with finished road paving) by 2050, “roughly 67% of forest cover and 40% of mammalian biodiversity there will be lost” (Soares-Filho et al. 2006). Figure 9 above only adds support to this study. Since 2005 when paving began, deforestation within 18 km of the road has skyrocketed. Once paving is complete, many expect the rate and extent of deforestation to sharply increase (Southworth et al. 2011).

CONCLUSION

Road ecology has a lot to offer to the scientific community, policy makers, and urban planners.

However, this research into Amazon road terminology demonstrates how confusion over road definitions and terms may reduce the utility of the literature. In some cases, several terms describe the same type of road (for instance, main-official-primary). At the same time, in other instances, a single term is used to describe different types of roads (for example, secondary).

The more defined and organized road ecology is as a discipline, the more it can help minimize environmental and social concerns. This research's newly created typology narrows road types into three main categories (primary, secondary, and tertiary) while still allowing for flexibility to further specify subtypes (secondary *access* road). This typology may serve as a way to not only to compare and contrast previously published literature, but also to produce consistency in future published works. Additionally, more micro-scale studies can zero in on specific subtypes or systems (like logging by Uhl and Vieira (1989)) more successfully. Specific terms and definitions add fluidity to research and make studies and their findings more comprehensible and accessible.

Hopefully the typology presented here will not only allow road ecology to progress as a discipline, but also positively impact development policies. While environmental and socioeconomic impacts may differ across regions, the terminology used in road ecology should be as consistent as possible regardless of location. The possibility does exist that certain regions may have a road type not present in others, but, generally, studies utilize similar subtypes that can be uniformly labeled via a more standardized vocabulary. If this unification is accomplished, the goal of mitigating negative road impacts can more easily be discussed and enacted on a global scale.

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